Re-engineering Legacy Mission Scientific Software

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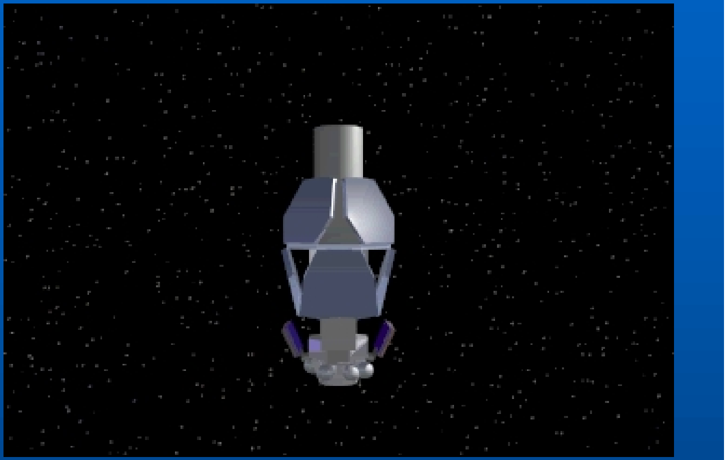
Modernizing Scientific Software

- **Legacy Software Has Value**
  - Generally well debugged with correct and trusted results
  - Actively used meeting end-user goals
- **Legacy Software Has Limitations**
  - Difficult to extend, modify, and support collaborative development
- **Rewriting Software Has Additional Costs**
  - Developing new verification/validation tests can be expensive
- **Abandon Legacy Code or Modernize It?**
  - If functionality is sound, legacy code can be wrapped in a modern interface where original code is mostly unmodified

Modernizing Scientific Software

- **CSMISS SET Activity**
  - Develop an incremental approach to re-engineer legacy systems
  - Examine how our methodology may benefit various JPL mission software projects
  - Demonstrate this for MACOS optical analysis software important to many NASA projects (D. Redding (385))

Software Re-engineering Benefits Optics Modeling for Mission Critical Projects



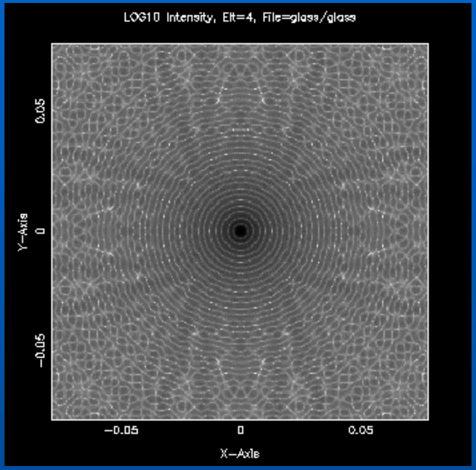
Next Generation Space Telescope

NASA Origin's program
NASA/GSFC/JPL

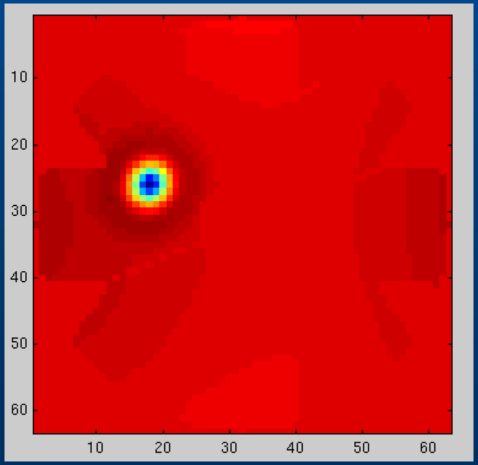
- **Current Results**
  - Methodology successfully applied & delivered to MACOS project
  - Meetings with JPL projects including future work involving the Navigation and Flight Mechanics Section

MACOS Overview

- **Modeling and Analysis for Controlled Optical Systems (MACOS/SMACOS)**
  - Developed by David Redding, and others, from Optical Systems Modeling Group (385)
  - Provides powerful optical analysis tools and a unique capability for system-level design tasks
- **Short List of Features**
  - Modeling optics on dynamic structures, deformable optics, and controlled optics
  - Efficient general ray-trace capabilities
  - Integrated support with other tools to create an end-to-end instrument system model



Modeling and Analysis of Controlled Optical Systems (MACOS) Program



MACOS Project Goals

- **Enhancement to benefit from modern software engineering techniques**
  - New features of Fortran 90/95 standard
  - Dynamic memory
  - Problem domain based design
  - Reorganization to promote collaborative development

Protect existing investment in software development and efficiency while benefiting from increased safety, organization, and extensibility

Technology

- **Fortran 90/95 Features Modernize Programming**

Modules
Encapsulate data and routines across program units

Interfaces
Verifies argument types in procedure calls

Array Syntax
Simplifies whole array, and array subset, operations

Use-Association
Controls access to module content

Derived Types
User-defined types supporting abstractions in programming

Pointers/Allocatable Arrays
Supports flexible/dynamic data structures

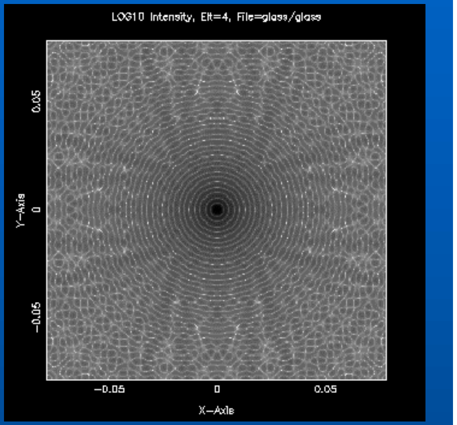
Backward compatible with Fortran 77

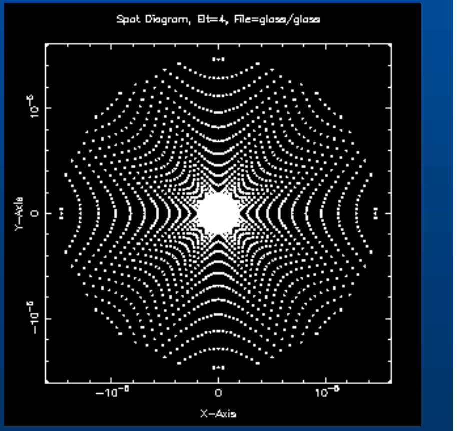
FOR MORE INFO...

Fortran 90 Programming. Ellis, Philips, & Lahey; Addison Wesley, 1994
http://www.cs.rpi.edu/~szymansk/oof90.html

Technology

- **Preserve existing software, yet transform for new development**
  - Create wrapper/interface layer to original code
  - Support abstraction-based programming via interfaces
  - Gradual/selective replacement of data structures
- **Benefits**
  - Software remains in use during modification
- **Not automatic, but largely mechanical...**
  - Automation projects, with limited capabilities, underway

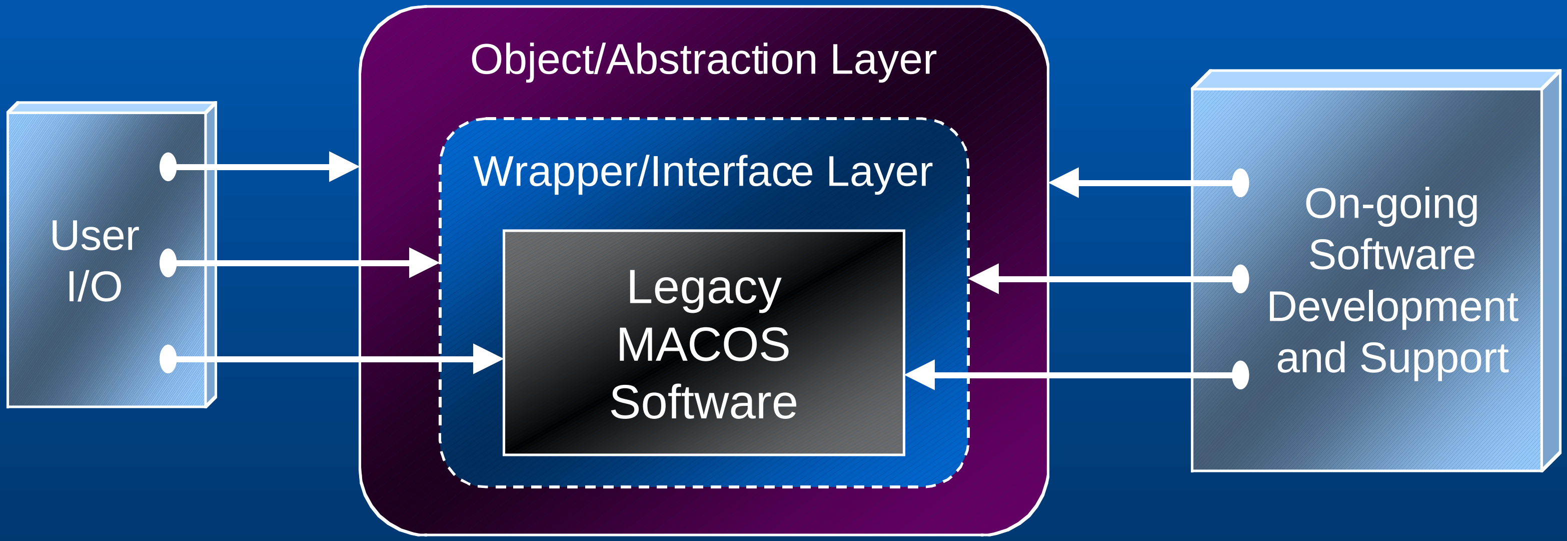




Important as more ambitious codes are developed and maintained

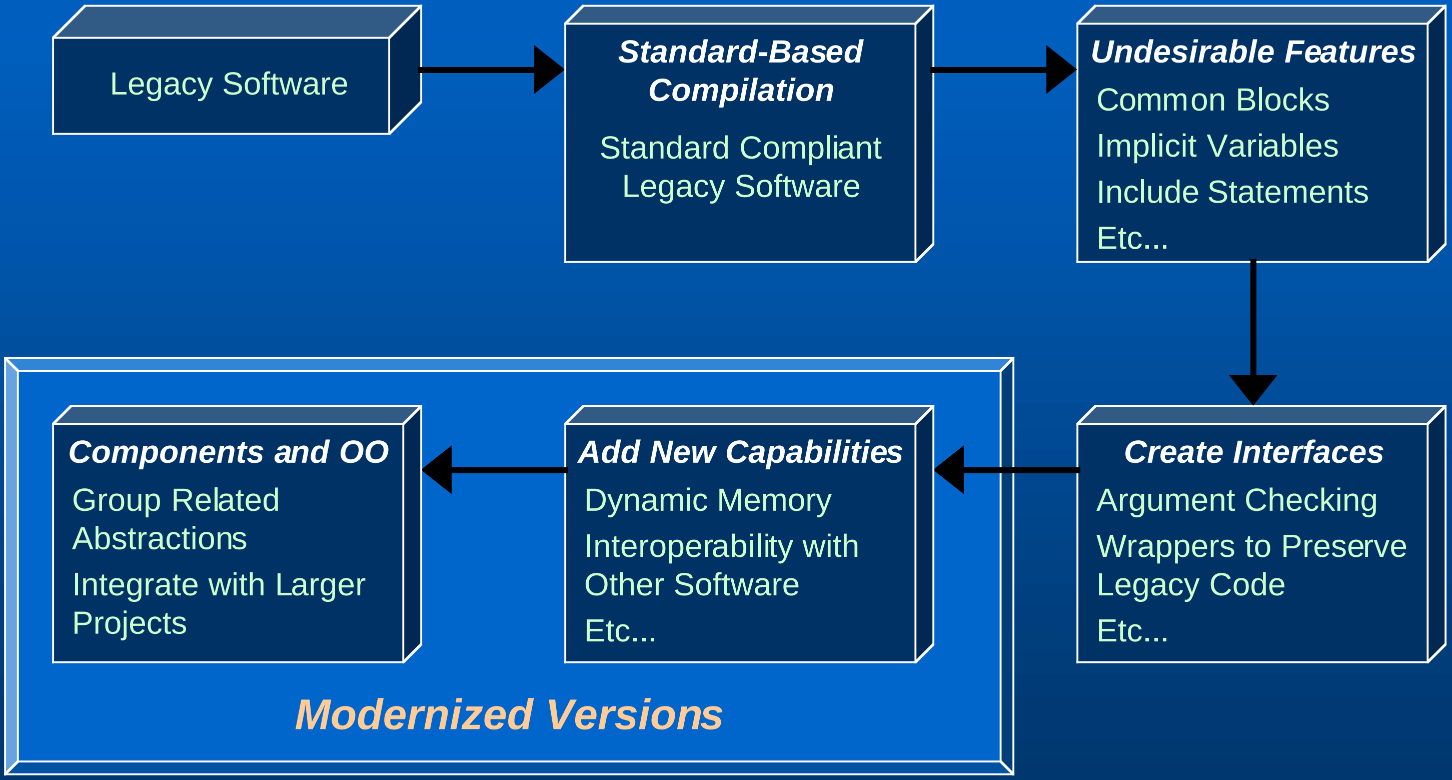
Modernization Process

- **Efficient interaction among MACOS, interfaces, abstraction layer, and user I/O**



Allows safe interaction with a legacy code

Modernization Process



Stages can vary based on original design of legacy software

Addressing Undesirable Features

- **Common Blocks**
  - Inhibit dynamic memory, exposure discourages code sharing, modification causes inadvertent errors

```
! Original COMMON Block in file
  common.inc
  real arg1(10,10), arg2(10,10)
  logical arg3
  integer arg4
  COMMON /BLOCK1/ arg1, arg2, arg3, arg4
  SAVE /BLOCK1/

  subroutine foo()
  include ‘common.inc’
  ...
  end subroutine
```

```
! Modernized version in common.f90
  MODULE common_block1
   implicit none
   save
   real, dimension(10,10) :: arg1, arg2
   logical :: arg3
   integer :: arg4
  END MODULE common_block1

  subroutine foo()
  use common_block1
  ...
  end subroutine foo
```

Conversion to modules is straightforward and brings many benefits...

Building Standard Wrappers

- **Interfaces**
  - Simplifies argument lists
  - Performs argument checks
  - Supports wrappers preserving legacy code

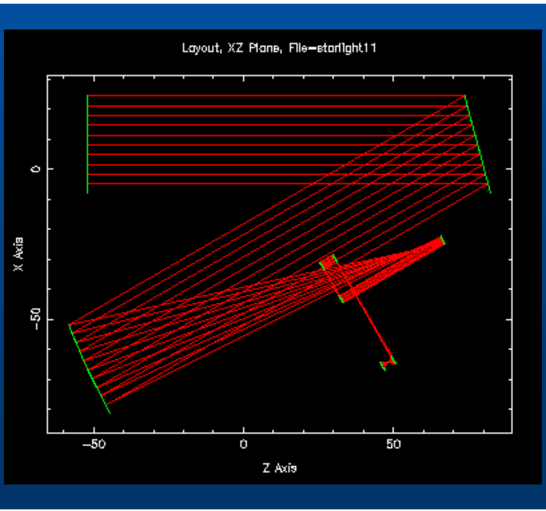
```
! Interface Module
  MODULE interface_module
   use common_block1
   implicit none
   save
   interface
     subroutine foof77(arg1, arg2, dim1)
       real, arg1(dim1, dim1)
       integer :: dim1
       logical :: arg2
     end subroutine
   end interface
  CONTAINS
  subroutine foof90(arg1, arg2)
   real, dimension(:,:) :: arg1
   logical :: arg2
     call foof77(arg1, arg2, size(arg1,1))
  end subroutine foof90
  END MODULE interface_module
```

- A simple example, but significant for complex procedures
- Modernized features can be applied at the interface/wrapper level

Building Standard Wrappers

- **Dynamic Memory**

```
! Legacy F77 include of COMMON data
   parameter (mdttl=128)
   integer nElt, RayID(mdttl, mdttl)
   COMMON /EltInt/ nElt, RayID,...
   SAVE /EltInt/
```



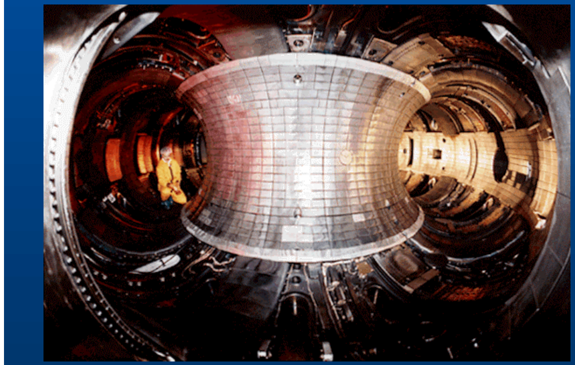
- Direct conversion of static data to dynamic data

```
! New Module for COMMON data with
  Dynamic Memory and Constructor
  Support
  MODULE elt_common
   implicit none
   save
   integer :: nElt, mdttl = 128
   integer, allocatable :: RayID(:,:)
  CONTAINS
! Constructor
   subroutine new_elt_common()
     allocate( RayID(mdttl, mdttl) )
   end subroutine new_elt_common
  END MODULE elt_common
! Dynamic Allocation from Main Program
  PROGRAM example
   use elt_common
   implicit none
   call new_elt_common()
   ...
  END PROGRAM example
```

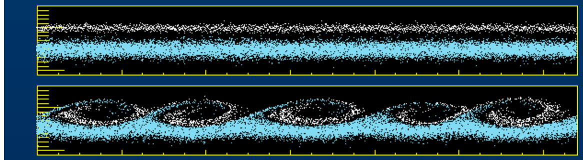
Building Standard Wrappers

- **Object-Oriented Design**
  - Legacy routine is wrapped by a simplified OO interface supporting dynamic components
  - Main program must call wrapper

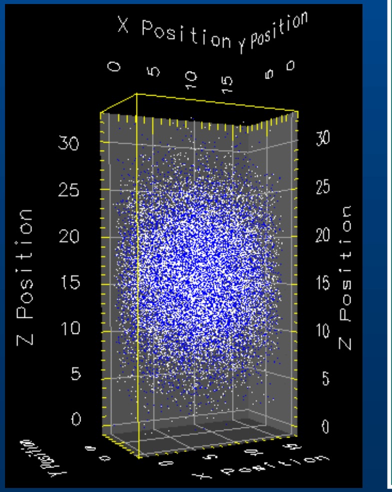
Tokamak Fusion Test Reactor (PPPL)



Beam-Plasma Instability



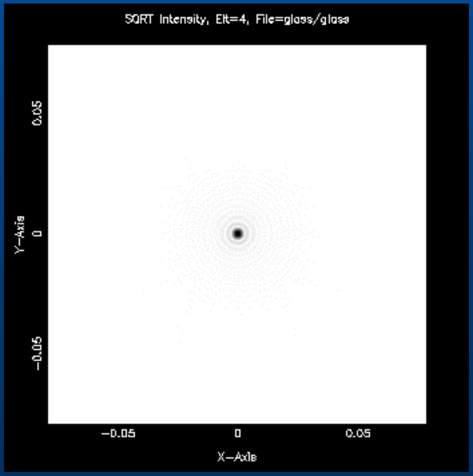
Free Expansion

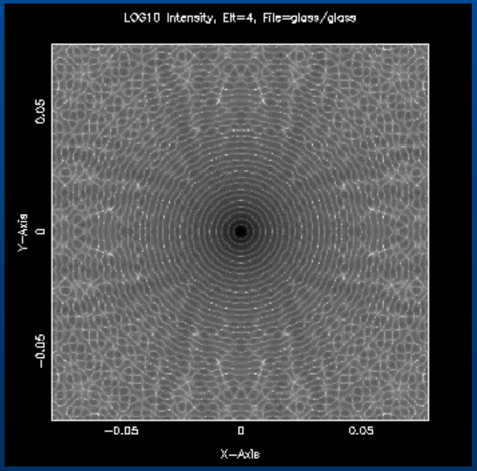


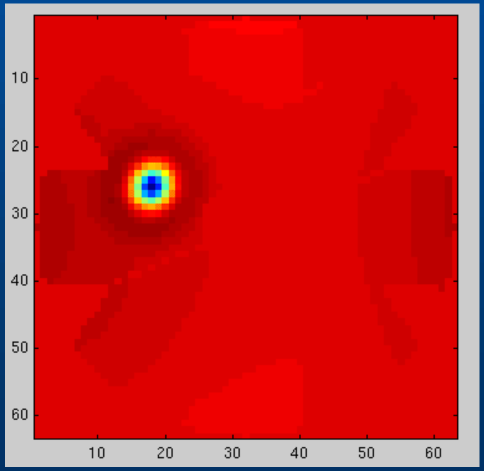
```
!  Encapsulation for Object-Design
  MODULE plasma_class
   type species
     real, dimension(:,:), pointer :: coords
     real :: charge_to_mass, kinetic_energy
   end type species
  CONTAINS
!  Using a legacy routine via an OO Wrapper
   subroutine w_push(particles, force, dt)
   type (species) :: particles
   real, dimension(:) :: force
   real :: dt, qbm, wke
   integer :: ndim, nparticles, nx
     ndim = size(particles%coords,2)
     nx = size(force)
     qbm = particles%charge_to_mass
     wke = particles%kinetic_energy
     call push(particles%coords, force, &
               qbm, wke, ndim, nparticles, &
               nx, dt)
   end subroutine w_push
  END MODULE plasma_class
```

Impact on MACOS

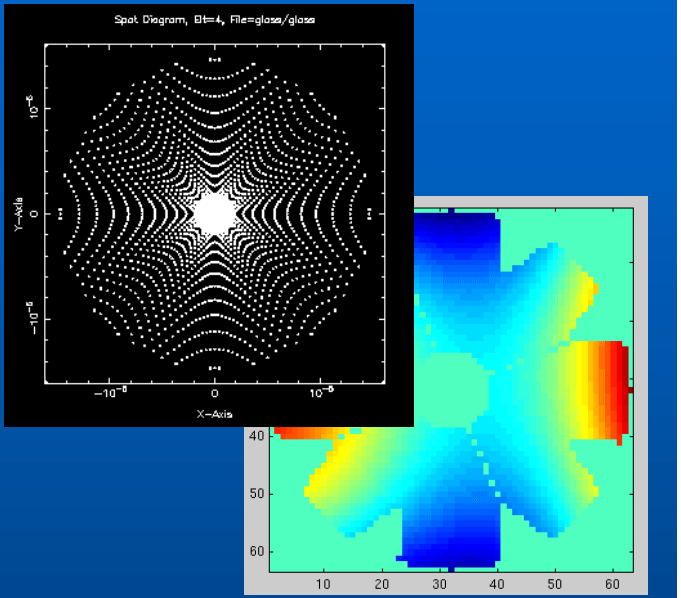
- **Improved Functionality**
  - System supports dynamic memory
  - Long-lasting subtle bugs corrected
  - More simple interfaces
  - Supports standardized language features







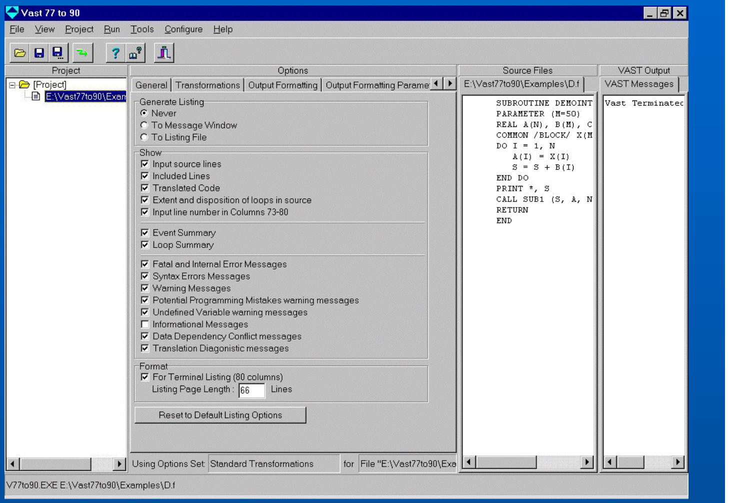
Modernization Experiences



- **Legacy Code Characteristics**
  - ~67,200 lines of Fortran 77
  - Distributed across ~60 files
  - Must interact with MATLAB and FFTW
  - ~765 Procedures
- **Modernized Code Characteristics**
  - ~3,500 additional lines of Fortran 90 (mainly interfaces)
    - 10 new modules, 28 required legacy interfaces, ~540 use statements replaced common block includes
  - .5 work year effort without participation of original authors
    - 2-3 times improvement expected when original authors participate
    - Speed/Performance comparable to original
  - The modernization process improved the code

Current Work Directions

- **Partial Automation**
  - Examine S/W tools for building interfaces automatically
- **Object-Oriented Interfaces**
  - Research how modernization process can add object-oriented concepts to legacy software
- **Define Software Architecture**
  - Separate GUI from physics
  - Extend concepts to other languages
- **Software Integration with NGST**
  - Moving modernized code into executive software that remotely drives the optical testbed hardware at GSFC



Generate Listing
● Never
○ To Message Window
○ To Listing File

Show
☑ Input source lines
☑ Included Lines
☑ Translated Code
☑ Extent and disposition of loops in source
☑ Input line number in Columns 73-80

☑ Event Summary
☑ Loop Summary

☑ Fatal and Internal Error Messages
☑ Syntax Errors Messages
☑ Warning Messages
☑ Potential Programming Mistakes warning messages
☑ Undefined Variable warning messages
☐ Informational Messages
☑ Data Dependency Conflict messages
☑ Translation Diagonistic messages

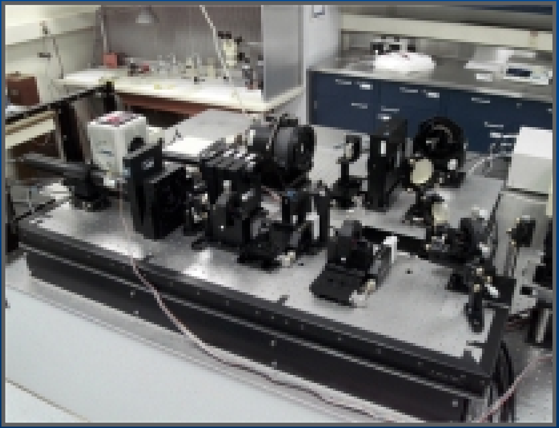
Format
☑ For Terminal Listing (80 columns)
Listing Page Length : 66 Lines

Using Options Set: Standard Transformations for File "E:\Vast77to90\Exa

```
      SUBROUTINE DEMOINT
      PARAMETER (M=50)
      REAL A(N), B(M), C
      COMMON /BLOCK/ X(M
      DO I = 1, N
         A(I) = X(I)
         S = S + B(I)
      END DO
      PRINT *, S
      CALL SUB1 (S, A, N
      RETURN
      END
```

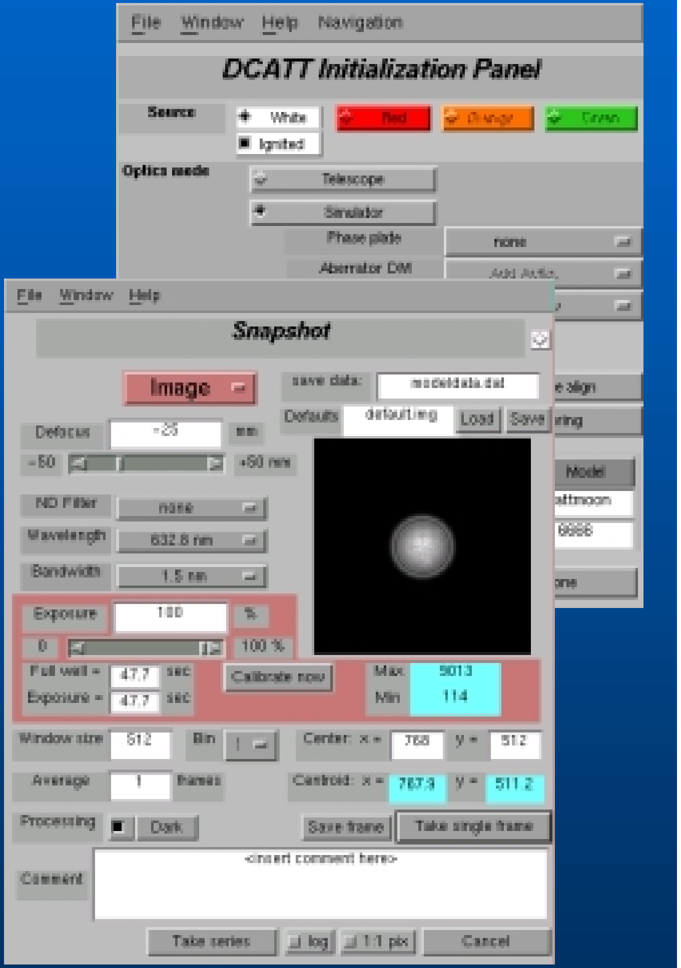
```
Vast Terminatec
```

V77to90.EXE E:\Vast77to90\Examples\D.f



Current Work Directions

- **Optical Systems Modeling Group**
  - Integration of new MACOS software with executive code to drive GSFC optical testbed remotely from JPL



DCATT Initialization Panel

Source: ● White ■ Ignited

Optics mode: ● Simulator

Phase plate: none

attmoon

6666

Snapshot

save data: modeldata.dat

Defaults: default.img

Defocus: -25 mm (-50 … +50 mm)

ND Filter: none

Wavelength: 632.8 nm

Bandwidth: 1.5 nm

Exposure: 100 % (0 … 100 %)

Full well = 47.7 sec

Exposure = 47.7 sec

Max: 5013

Min: 114

Window size: 512

Bin: 1

Center: x = 768 y = 512

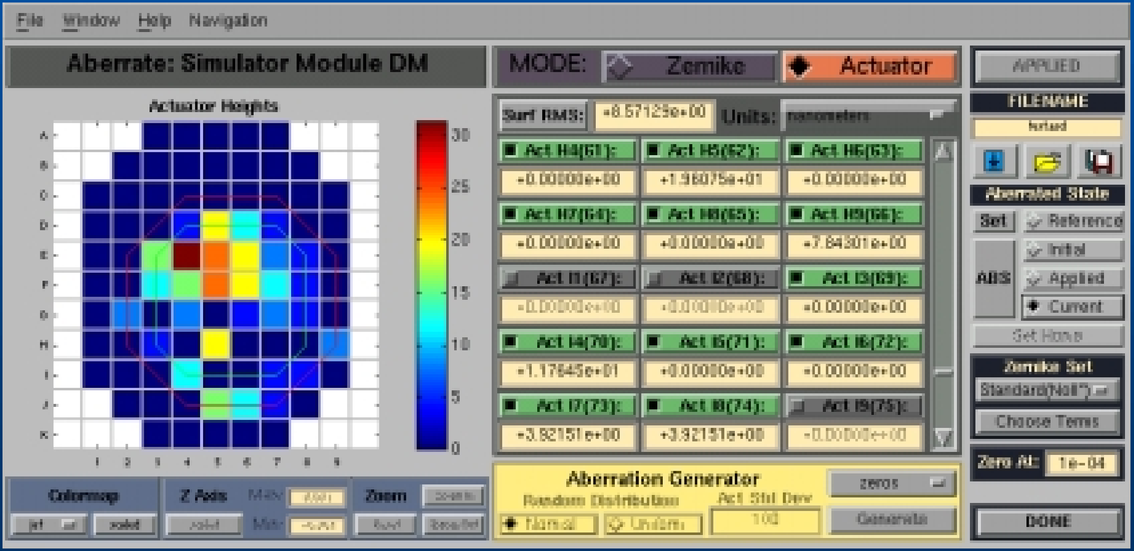
Average: 1 frames

Centroid: x = 767.9 y = 511.2

Processing: ■ Dark

Comment: <insert comment here>

□ log □ 1:1 pix



MODE: ◇ Zernike ◆ Actuator

Surf RMS: +8.57125e+00 Units: nanometers

■ Act H4(61):	■ Act H5(62):	■ Act H6(63):
+0.00000e+00	+1.96075e+01	+0.00000e+00
■ Act H7(64):	■ Act H8(65):	■ Act H9(66):
+0.00000e+00	+0.00000e+00	+7.84301e+00
□ Act I1(67):	□ Act I2(68):	■ Act I3(69):
+0.00000e+00	+0.00000e+00	+0.00000e+00
■ Act I4(70):	■ Act I5(71):	■ Act I6(72):
+1.17645e+01	+0.00000e+00	+0.00000e+00
■ Act I7(73):	■ Act I8(74):	□ Act I9(75):
+3.92151e+00	+3.92151e+00	+0.00000e+00

FILENAME: hirfaed

Aberrated State: Set ○ Reference; ABS ○ Initial ○ Applied ● Current

Zernike Set: Standard(Noll)

Zero At: 1e-04

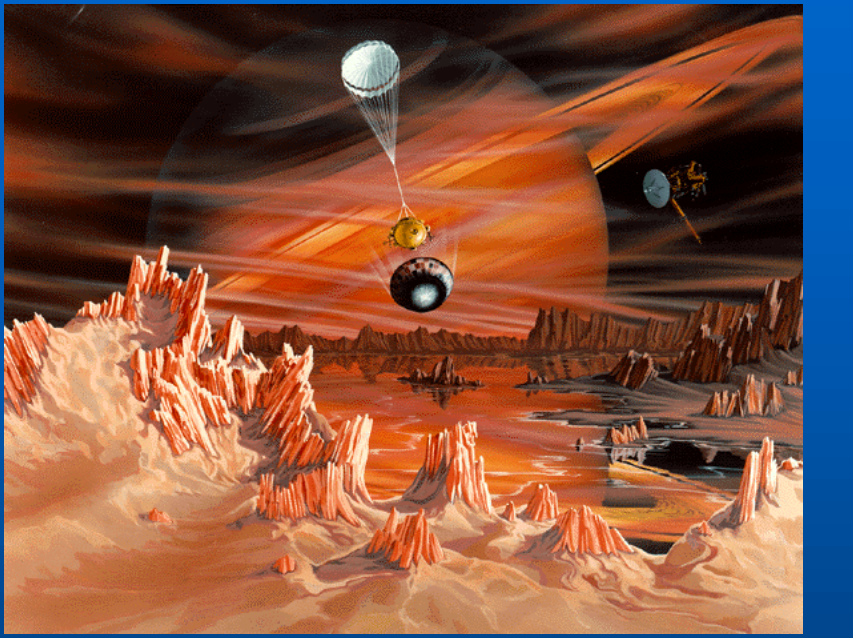
Aberration Generator: zeros

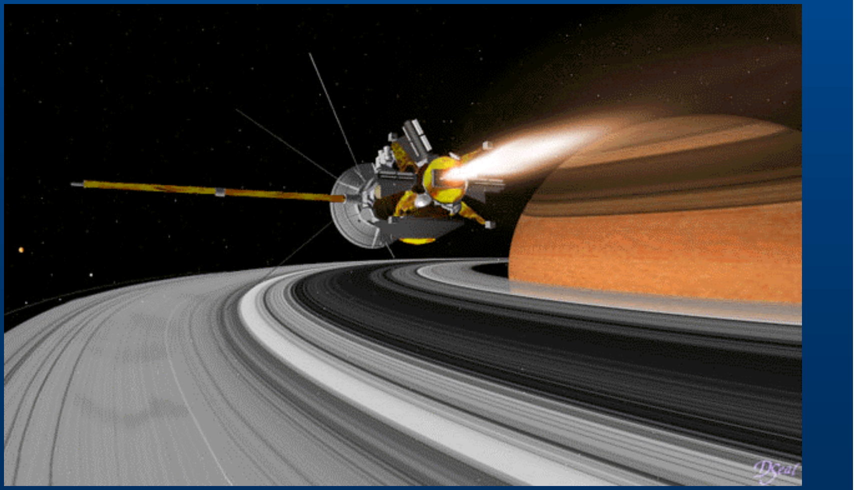
Random Distribution: ● Normal ○ Uniform

Act Std Dev: 100

Current Work Directions

- **Navigation Software Development Group**
  - Support over 6 MLOC in Fortran 77 and C
  - Require migration to F90/95 since F77 will be discontinued on current platform
  - Must support current, and new, missions without abandoning existing work
  - Cannot afford delays in schedule, but new development must continue
  - Successfully applied this process to parts of their code





Benefits of Re-engineering Methodology

- **Legacy codes still have value, but extending that functionality has become more important**
- **Modern codes require...**
  - Greater complexity and multiple authors
  - Dynamic features and flexible design
- **Build modern superstructure while code remains in use**
  - Data abstraction and information hiding are key to limiting exposure of unnecessary details
  - Modern language features reduce inadvertent errors
- **Wrappers can extend functionality**
  - Verify preconditions, measure performance, etc...

More Information

- **On the Web...**
  - http://hpc.jpl.nasa.gov/PEP/nortonc/csmiss.html
    - White Papers, FY 2000 Final Report, etc...
- **Acknowledgment**
  - Center for Space Mission Information and Software Systems
  - Observational Systems Division
    - High Performance Computing Group
    - Optical Systems Modeling Group
  - Navigation and Mission Design Section
    - Navigation Software Group